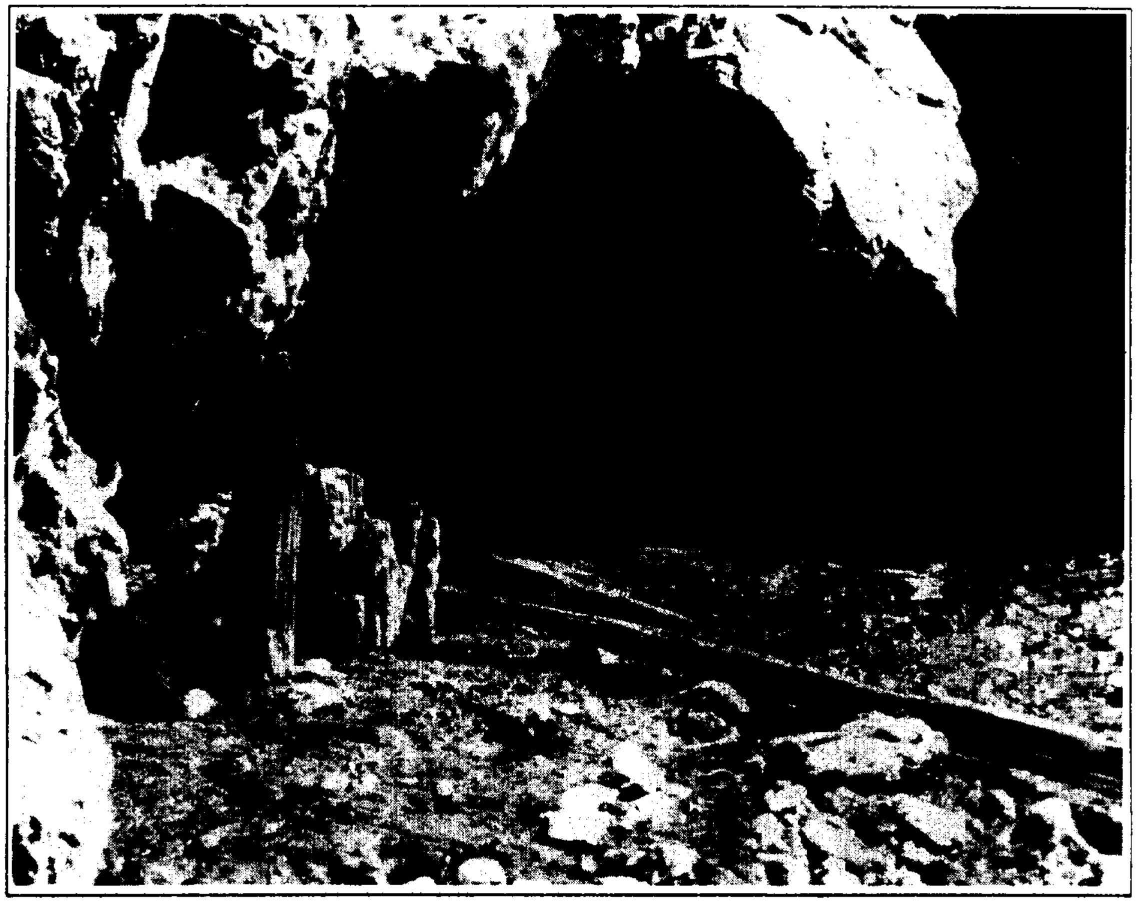

Report to the Legislature
on
ACID-GENERATION POTENTIAL TESTS

90 - 18CWP

December 1990

WATER RESOURCES CONTROL BOARD
STATE OF CALIFORNIA

STATE OF CALIFORNIA
George Deukmejian, Governor

ENVIRONMENTAL AFFAIRS AGENCY
Jananne Sharpless, Secretary

STATE WATER RESOURCES
CONTROL BOARD
P.O. Box 100
Sacramento, CA 95812-0100
(916) 322-3132

COVER:
Acidic Drainage From The Golinsky Mine
Adit, Shasta Co.

SOURCE:

Rick Humphreys, State Board

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By Richard D. Humphreys
DIVISION OF CLEAN WATER PROGRAMS

WATER RESOURCES CONTROL BOARD
STATE OF CALIFORNIA

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ACID-GENERATION POTENTIAL TESTS
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EXECUTIVE SUMMARY

Assembly Bill 1413 (Tanner) directed State Water Resources Control Board (State Board) staff to evaluate analytical tests currently used to assess the acid-generation potential of mining waste and report the findings to the California Legislature on or before January 1, 1991.

Staff's evaluation was based primarily on a review of the literature describing acid-generating processes, testing, and field and laboratory studies of test performance and reliability. Staff also consulted with professionals in industry and other government agencies who are investigating the phenomenon of acid-generation, acid-generation testing, and acid-generation control.

Chapter I describes the physical processes of both acid generation and acid neutralization as well as the tests used to assess the acid-generation potential of mining waste. Chapter II describes both static and kinetic testing methods in detail. Finally, Chapter III summarizes the conclusions of the report. Currently available tests fall into two fundamentally different categories: static tests and kinetic tests. Static tests are laboratory bench tests that measure the total acid-generation potential from the sulfur-bearing minerals and total acid-neutralizing potential from the acid neutralizing minerals present in mining waste. If the simplistic assumptions upon which the tests are based hold, they can provide generally reliable predictions about acid-generation potential.

Kinetic tests are laboratory or field tests that evaluate the acid-generation potential of mining waste by subjecting the waste to accelerated weathering under controlled conditions that induce the waste to generate acid. In addition, kinetic tests provide insight into the chemical characteristics of the leachate produced, the reduction of the neutralization potential of a waste with time, and the lag time in the onset of acid generation. Kinetic tests, however, are time consuming, and thus, expensive to complete. Additionally, because there is no standard test duration, sometimes tests have been terminated before data necessary to evaluate acid generation is acquired (Ferguson, personal communication, Sept. 7, 1990).

Because of their simplistic assumptions, static tests should not be used alone to assess the acid-generation potential of mining waste. Static tests are more suited for a waste screening role, and their results should be confirmed by kinetic tests. Kinetic tests are more reliable than static tests in determining whether a mining waste will or will not generate acid; moreover, they can provide insight into both when a waste will begin to generate acid and the magnitude of the acid production. Consequently the most useful information concerning the potential threat mining waste poses to water quality will come from kinetic tests. Kinetic tests produce complex data that is difficult to interpret; therefore, the results of these tests should be evaluated by experienced professionals who understand the processes that these tests attempt to model. Our evaluation indicated that testing programs employing both static and kinetic tests are best suited for assessing the acid-generation potential of mining waste in California.

Recommendations

New tests and modifications to existing tests are being developed in Canada by consultants under contract with Environment Canada, at several Canadian and American universities, and at the United States Bureau of Mines. These entities have specialists; analytical equipment; access to existing data bases and samples; and, most importantly, funding for the pursuit of this work. Consequently, there is no need for the State Board to independently develop a new test for assessing the acid-generation potential of mining waste.

CHAPTER I -- PHYSICAL PROCESSES

For the purposes of this report, the term "acidic leachate" is used to describe the leachate that results from the natural oxidization of sulfide minerals contained in rock that is exposed to air and moisture. Sources of acidic leachate include: (1) mining waste (e.g., overburden, waste rock, heap leach ore piles or waste piles, stockpiles, and mill tailings; see Figure 1); (2) underground mines (e.g., the Iron Mountain mine in Northern California and many coal mines in the Eastern United States); (3) open pit mines; and (4) large cuts at construction projects that expose sulfide minerals (e.g., at the Halifax, Nova Scotia airport construction project [Guilcher, M., 1987]).

Mining waste contains sulfur usually as sulfides and sulfates, but rarely as elemental sulfur. Sulfides are responsible for the long-term acid-generation potential of a particular waste. Sulfates are usually the result of past sulfide oxidation. As such, they indicate historic acid generation. They also can create acidic conditions immediately on contact with water.

Acid-Generation Process

For practical purposes, the three principal ingredients in the acid-generation process are oxygen, water, and reactive sulfide minerals (chiefly the iron disulfides pyrite, marcasite, and pyrrhotite). For ease of reference, all iron disulfides will be referred to as pyrite.

The inorganic acid generation process is modeled as follows: Pyrite is oxidized directly by oxygen producing ferrous iron and acidity; this step is followed by iron oxidation. Finally, ferric iron produced by the preceding step is hydrolyzed and precipitated at high pH. These three relatively slow reactions comprise the initial stage of the acid-generation process described by Kleinman et al (1981). The initial stage persists as long as the pH in the immediate vicinity of the reacting pyrite is only moderately acidic ($pH > 4.5$). If pH declines, however, iron hydrolysis would also decline, providing ferric iron for oxidizing pyrite. Ferric iron is a much more effective oxidant than oxygen for oxidizing pyrite. The presence of ferric iron causes rapid acid production and becomes the dominant acid-producing oxidant at low pH (Ferguson and Erickson, 1988).

It is generally agreed that the bacterium Thiobacillus ferrooxidans biologically catalyzes the acid-generation reactions, thereby exerting the dominant control over the acid-generation rate. Laboratory experiments have shown that this bacteria can increase the acid-production rate by several orders of magnitude. T. ferrooxidans apparently catalyzes the oxidation of ferrous to ferric iron, thereby providing a rapid reaction pathway for pyrite oxidation. Additionally, both T. ferrooxidans

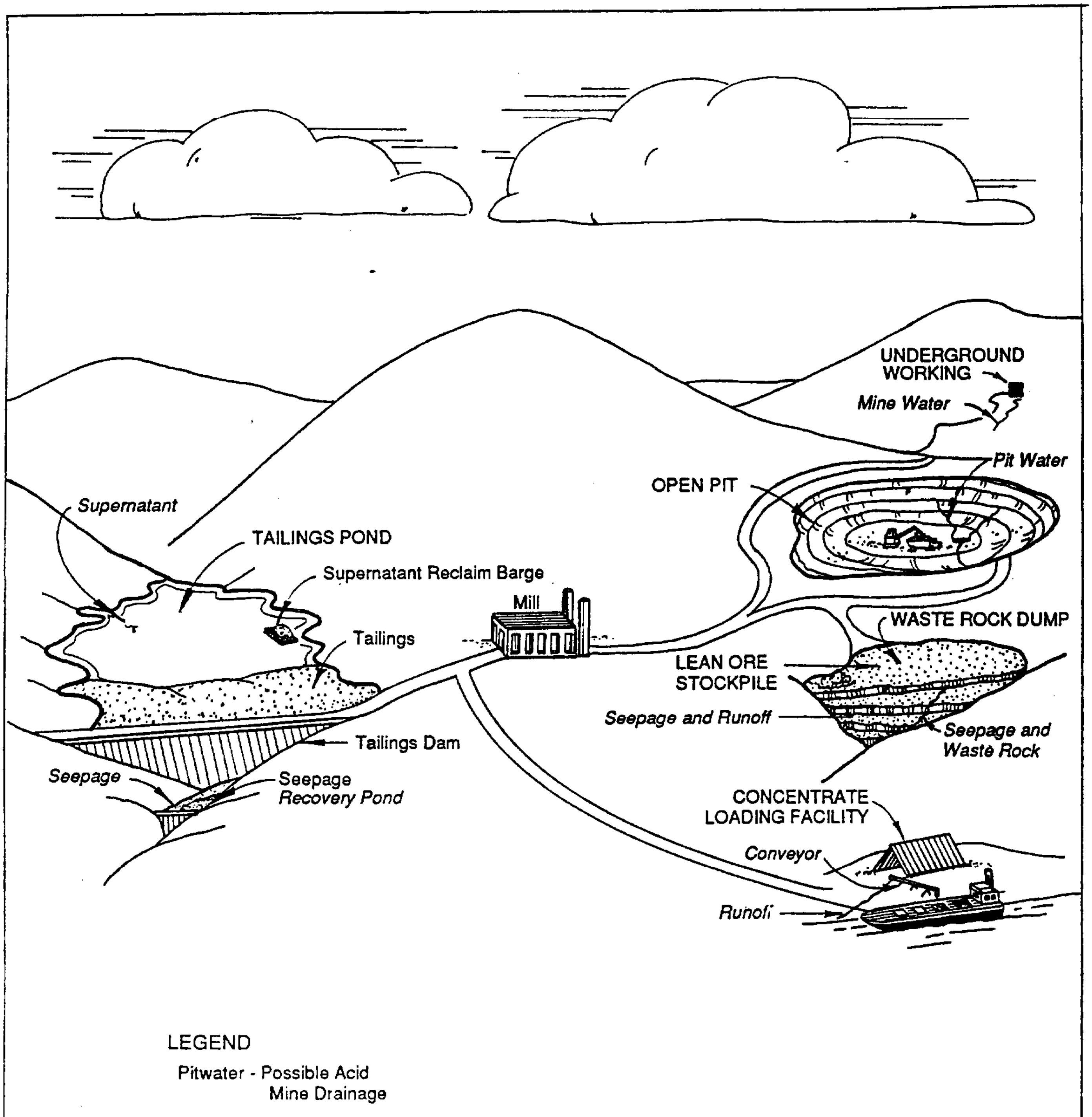

FIGURE 1
MAJOR COMPONENTS OF A METAI MINE AND SOURCES OF ACID MINE DRAINAGE
(Ferguson and Erickson, 1988)

DWG. 3415

and ferric iron oxidize less-reactive sulfides which are characteristic of metallic ore bodies (see Table 1). The oxidation of these other sulfides contributes heavy metals to the acid leachate (Ferguson and Erickson, 1988).

Non-biological factors can affect the acid-generation rate and appear to be important prior to the onset of biologically controlled acid generation. These factors include the type and amount of pyritic minerals present, the crystallinity of these minerals (Caruccio, F. T., 1975), the surface area available for reaction, and the nature of crystal lattice bonds (Doyle, 1990). Reaction rates are also governed by the availability of oxygen and water and are somewhat temperature-dependent, even though the acid-generation reactions are exothermic.

Acid-Neutralization Process

Acid generation can be forestalled if naturally occurring or added carbonate minerals such as calcite or lime dissolve and cause alkaline conditions within the susceptible material. Dissolution of carbonate minerals can raise the pH of water percolating through mine waste to levels that inhibit the oxidation of the pyrite present. Acid generation would then depend upon the leaching rate of the carbonate minerals and would begin when alkaline conditions could no longer be maintained by the dissolution of the remaining carbonate minerals.

Carbonate minerals are sometimes characterized as strongly- or weakly-neutralizing on the basis of the rate that they neutralize acid. For example, the carbonate minerals calcite and dolomite will neutralize identical amounts of acid on a mass basis, but calcite is considered a stronger neutralizer because it neutralizes acid at a much greater rate.
Another factor affecting the acid-neutralization rate is the available surface area of the carbonate minerals present. For example, surface area will decrease and will diminish neutralization if the carbonate minerals develop coatings of insoluble sulfates and/or iron hydroxides when exposed to percolating acidic leachate.

Of relatively minor importance is the acid neutralization provided by some silicate minerals, chiefly feldspars. Again, these are slow neutralization reactions that can easily be overwhelmed by rapid pyrite oxidation (Lapakko, 1988).

TABLE 1

MINERAL SULFIDES OXIDIZED AND LEACHED BY MICROBES

Mineral sulfied	Microbe	Location	Refenence
Covellite (CuS)	T.ferrooxidans	Canada	Duncan and Trusell (1964)
Chalcocite (Cu_2S)	T.ferrooxidans	Canada	Duncan and Trusell (1964) Bryner and Jameson (1958)
Bornite (Cu_5FeS_4)	T.ferrooxidans	Canada	Duncan and Trusell (1964)
Chalcopyrite ($CuFeS_2$)	T.ferrooxidans	Canada	V.I. Ivanov et al.(1961)
T.ferrooxidans	Canada	Duncan and Trusell	(1964)
Cu and Co ores (S)	T.thiooxidans	Canada	Sutton and Corrick (1961)
CuS	T.thioparus	Canada	Sokolova (1960)
CuS (coal)	T.ferrooxidans	Canada	Kuznetsov (1963)
Marcastite (FeS_2)	T.ferrooxidans	Russia	Lyalikova (1961)
Pyrite (FeS)	T.ferrooxidans	Russia	Lyalikova (1961) V.I. Ivanov et al.(1961) Bryner and Jameson (1958)
Millerite (NiS)	T.ferrooxidans	Russia	Duncan and Trusell (1964)
Phyrrhotite (FeS)	Arthrobacter	Russia	Ehrlich (1963)
Sphalerite (ZnS)	Arthrobacter	Russia	Ehrlich (1963) V.I. Ivanov et al.(1961)
Galena (PbS)	Arthrobacter	Russia	Ehrlich (1963)
Realgar (AgS)	Arthrobacter	Russia	Ehrlich (1963)
	Hymphomicrobium	Russia	Ehrlich (1963)
Cu_2S	T.ferrooxidans	Russia	Ehrlich (1963)
Molybenite (MoS_2)	T.ferrooxidans	Russia	Bryner and Jameson (1958)
S (elemental)	T.thiooxidans	Russia	Parker and Prisk (1953)
	T.concretivorus	Russia	Parker and Prisk (1953)
	T.thioparus	Russia	Parker and Prisk (1953)
H_2S	T.concretivorus	Russia	Parker and Prisk (1953)

(from Zajic, 1969)

CHAPTER II -- TESTING METHODS

Static Tests

The following static tests measure both the total acid-generation potential (from the sulfur-bearing minerals present) and the total acid-neutralizing potential (from the acid-neutralizing minerals present) of mining waste by laboratory bench testing. The assumptions underlying these tests are that the waste is homogeneous, that the full acid-producing and acid-neutralizing potentials of the minerals will be realized, and that the rates of acid generation and acid neutralization are identical. Descriptions of the tests that follow are paraphrased, with permission, from Volume One of the "Draft Acid-Rock Drainage Technical Guide", prepared by Steffan, Robertson, and Kirstan Inc., (1989).

1. Total Sulfur

Objectives:
To determine the total sulfur content of a sample and to calculate the maximum potential acidity.

Description of test:
Total sulfur is determined by incinerating the sample in a LECO furnace. Maximum total acidity in units of kilograms of calcium carbonate equivalent/tonnes of sample is calculated by multiplying the sulfur percentage of the sample relative to its mass by 31.25. The foregoing conversion factor is theoretical and is based on geochemical assumptions which are dependent on simplified acid-generating conditions.

Advantages:
The method is widely used and proven. The theoretical maximum amount of acidity that could be produced can be calculated. The total sulfur measurement provides confirmation of cumulative quantities from other mineral specific tests for sulfur.

Disadvantages:
Acid-generating and nonacid-generating sulfur species are not differentiated, and acid-generation rates are not predicted.

2. Sulfur Species

Objectives:
To determine the sulfide, acid-leachable sulfate, and nonleachable sulfur content of a sample and to calculate potential acidity based on total sulfide.

Description of test:

Sulfur species (sulfide, sulfate, elemental sulfur) are determined via acid extraction and precipitation; the sum of the species should equal the total sulfur content. Potential acidity in units of kilograms of calcium carbonate equivalent/tonnes of sample is calculated by multiplying the sulfide sulfur percentage by 31.25.

Advantages:

Potential acidity represents only the rapidly oxidized sulfide and does not include nonacid-generating forms of sulfur.

Disadvantages:

Highly reactive sulfides may be oxidized to sulfate by the test resulting in low estimates of acid-generation potential. Slowly oxidizing sulfur forms are not detected. Acid-generation rates are not predicted.

3. Reactive Sulfur

Objective:

To determine the acid-generating reactive sulfur content of a sample. Reactive sulfur is defined as the difference between total sulfur and sulfate sulfur. This definition assumes that all sulfide is highly reactive.

Description of test:

Reactive sulfur is determined by reaction with hydrogen peroxide. Potential acidity in units of kilograms of calcium carbonate equivalent/tonnes of sample is calculated by multiplying the reactive sulfur percentage by 31.25.

Advantage:

Potential acidity based on highly reactive sulfur can be determined quickly.

Disadvantages:

The method is in its development stage and has not been reliably verified. Less reactive, slowly oxidizing sulfur forms are not detected; consequently, acid-generation potential can be underestimated. Acid-generation rates are not predicted.

4. Gross Neutralization Potential

Objective:

To determine the maximum neutralization potential of a sample.

Description of test:

The total amount of neutralizing minerals in a sample is determined by treating the sample with a known excess of hydrochloric acid.

Advantages:

The maximum amount of neutralization potential of a sample may be determined, and the method is widely used.

Disadvantages:

The results (final pH of neutralization) cannot be readily correlated between the laboratory and the field. Acid-neutralization rates are not predicted.

5. Carbonate Analysis

Objective:

To determine the amount of strongly neutralizing, carbonate minerals in a sample.

Description of test:

Carbonate content is calculated from carbon dioxide gas evolved during acid digestion in an enclosed chamber.

Advantages:

Only the carbonate minerals which are generally capable of neutralizing pH to the range of 5-9 are determined. The method is used widely (and has proven to be reliable) for analyzing the carbonate content of soils, but it has only recently been employed for acid-generation prediction.

Disadvantages:

The detection limits are high; consequently, small amounts of carbonate minerals may not be detected. Some common, reactive sulfide minerals such as pyrite interfere with the results. Acid-neutralization rates are not predicted.

6. Low Detection Limit Carbonate Analysis

Objective:

To determine the amount of strongly neutralizing, carbonate minerals in a sample.

Description of test:

Carbonate content is calculated from carbon dioxide gas evolved during acid digestion in an enclosed syringe purged with nitrogen.

Advantages:

The test predicts the short-term neutralization of acidity. Only the carbonate minerals which are generally capable of neutralizing pH to the range of 5-9 are determined.

Disadvantages:

The method is not used routinely. The rates and extent of neutralization are not predicted.

7. Paste pH

Objectives:

To determine the pH value the sample can immediately produce upon contact with water and to indicate whether significant acid generation occurred prior to or during pH-paste analysis.

Description of test:

Paste pH is measured by an electrode; the paste is formed from water and powdered rock combined in a specific ratio.

Advantages:

The test is simple; and the measured pH indicates whether the sample readily produces acidity or alkalinity.

Disadvantages:

The duration of the acidic or alkaline condition of the sample cannot be predicted; and acid- or alkaline-generation rates are not predicted.

Provided that the simplistic assumptions of the foregoing tests hold, these tests can provide generally reliable predictions about acid-generation potential. There are instances, however, where these assumptions do not hold. For example, the average sulfur content of a mining waste may be low, but its concentration may vary spatially within the waste. In such cases, a static test may indicate that the waste has low acid-generation potential, when, in fact, the waste can readily generate acid (Backes, C.A., Pulford, I.D., Duncan, H.J., 1988). Because it is sometimes difficult to know whether the underlying assumptions of these tests are valid, it may be necessary to both limit these tests to certain types of mining waste and to confirm the results of these tests with kinetic testing.

Kinetic Tests

The following kinetic tests evaluate the acid-generation potential of mining waste by subjecting the waste to accelerated weathering under controlled conditions; these tests cause the waste to generate acid. They can be performed in either the laboratory or on-site. Laboratory testing, however, offers the following advantages: large numbers of samples can be tested, weathering can usually be accelerated to a much greater degree, and test conditions can be varied to a wide degree (Lawrence, 1990[2]). Descriptions of the tests that follow are paraphrased, with permission, from Volume One of the "Draft Acid-Rock Drainage Technical Guide", prepared by Steffan, Robertson, and Kirstan Inc. (1989).

1. B.C. Confirmation Test

Objective:
To confirm the results of static tests.

Description of test:
The sample is placed in a sulfuric acid solution of pH 2.5, inoculated with the bacterium Thiobacillus ferrooxidans, and shaken for three days. After three days more sample (one-half the weight of the original sample) is added and the sample is shaken for 24 hours. If pH is less than 3.5 or greater than 4.0, the test is terminated; otherwise, the sample is shaken for another 48 hours and the pH is recorded. If the sample pH remains below 3.5, the bacteria are assumed to be self sustaining and there is a strong possibility that acid production will occur.

Advantage:
The test is relatively simple.

Disadvantages:
The test apparently ignores or confuses the concepts of solid-liquid balance; buffering and neutralization; inorganic sulfide oxidation time, and the optimum pH range for bacterial activity, which may result in inaccurate assessments of acid-generation potential. Acid-generation rates are not predicted. Control techniques for acid generation cannot be tested. Newer techniques are more reliable.

2. Soxhlet Reactor

Objective:
To confirm the results of static tests.

Description of test:
The standard Soxhlet reactor recirculates deionized water through a sample for up to 192 hours. Variations include multiple intervals of sample drying. Water in the reactor reservoir is sampled for acid-generation reaction

products. To confirm the results of static tests the pH can be evaluated as follows:

- strongly acid generating if pH is less than 3.0,
- acid generating with possibly some neutralization if pH is between 3.0 and 5.0, and
- either not significantly acid generating or acid neutralization is overwhelming acid generation if pH is above 5.0.

Advantages:
The results are available after a relatively short time; to a limited extent, control options can be tested; and the test is relatively simple.

Disadvantages:
The results cannot be used to simulate natural conditions, the method is not widely used, the influence of bacteria on acid-generation rates cannot be monitored, and the method is still under development.

3. Shake Flasks

Objectives:
To determine the rate and temporal variations in acid generation, to determine temporal variations in water quality, to confirm the results of static tests, and to test some proposed control options.

Description of test:
The sample is placed in a flask and covered with water or nutrient solution. Flasks may be inoculated with *T. ferrooxidans*, and temperature may be varied. Flasks are shaken continuously and periodically sampled for acid-generation reaction products. General parameters for evaluating water quality changes include pH, sulfate, acidity, and metals. To confirm the results of static tests the pH can be evaluated as follows:

- strongly acid generating if pH is less than 3.0,
- acid generating with possibly some neutralization if pH is between 3.0 and 5.0, and
- either not significantly acid generating or acid neutralization is overwhelming acid generation if pH is above 5.0.

Advantages:

Acid-generation and neutralization rates, under more-or-less natural conditions, can be evaluated; the effects of various environmental factors can be tested during the same time interval; temporal variations in acid-generation and neutralization rates can be determined; control options such as adding limestone can be evaluated; the influence of bacteria can be determined; and the test is relatively simple.

Disadvantages:

Bacteria may not acclimatize to the sample, the relatively high water content may inhibit acid production, a test may need to run for a long time to meet program objectives, and interpreting the data is complex.

4. Humidity Cell

Objectives:

To determine the rate and temporal variations in acid generation, to determine temporal variations in water quality, to confirm the results of static tests, and to test some proposed control options.

Description of test:

Samples are subjected to humid air flow and periodically washed with distilled water. Variations include inoculating the sample with *T. ferrooxidans;* subjecting the sample to wet/dry cycles; submerging the sample, either fully or partially; and passing humid air up through a sample. Chemical analysis of each periodic rinse will indicate the incremental change in acid generation, sulfide oxidation, neutralization, and metals release. General parameters for evaluating water quality changes include pH, sulfate, acidity, and metals. To confirm the results of static tests the pH can be evaluated as follows:

- strongly acid generating if pH is less than 3.0,
- acid generating with possibly some neutralization if pH is between 3.0 and 5.0, and
- either not significantly acid generating or acid neutralization is overwhelming acid generation if pH is above 5.0.

Advantages:

Acid-generation and neutralization rates in a simulated moist, oxygenated environment can be evaluated; the effects of various environmental factors such as saturated or submerged conditions can be tested during the same time interval; temporal variations in acid-generation and neutralization rates can be determined; control options such as adding limestone can be evaluated; the influence of bacteria can be determined; the test is widely used and has been compared to other predictive tests to demonstrate reliability; and the test is relatively simple.

Disadvantages:
Bacteria may not acclimatize to the sample, a test may need to run for a long time to meet program objectives, and interpreting the data is complex.

5. Columns/lysimeters

Objectives:
To determine the rate and temporal variations in acid generation, to determine temporal variations in water quality, to confirm the results of static tests, and to test treatment/mitigation options.

Description of test:
A known amount of sample is placed in vertical columns and water or water-based solution is flushed through the sample. Variations include inoculating the sample with T. ferrooxidans, subjecting the sample to wet/dry cycles, changing the degree of saturation of the sample, and reversing the flow of water up through a sample. Chemical analysis of water actively flushing a sample will indicate the immediate rates of acid generation, sulfide oxidation, neutralization, and metals release. General parameters for evaluating water quality changes include pH, sulfate, acidity, and metals. To confirm the results of static tests, the pH can be evaluated as follows:

- strongly acid generating if pH is less than 3.0,
- acid generating with possibly some neutralization if pH is between 3.0 and 5.0, and
- either not significantly acid generating or acid neutralization is overwhelming acid generation if pH is above 5.0.

Advantages:
Acid-generation and neutralization rates, under various environmental conditions, can be determined; temporal variations in acid-generation and neutralization rates can be determined; control options such as adding

limestone can be evaluated; the influence of bacteria can be determined; the test is widely used and apparently reliable.

Disadvantages:

This test is moderately complex to run compared to other laboratory kinetic tests, tests may be difficult to set up and run because of the complexity of soil/water characteristics in the columns, bacteria may not acclimatize to the sample, a test may need to run for a long time to meet program objectives, and interpreting the data is complex.

6. On-site Rock Piles

Objectives:

To determine the rate and temporal variations in acid generation, to determine temporal variations in water quality, to confirm the results of static tests, to test control options, and to determine the effect of on-site conditions on acid-generation rates and water quality.

Description of test:

A large quantity of sample is placed on an impervious foundation at the mine site and allowed to weather under natural conditions. Periodically, the volume of seepage from the pile is measured and a sample is collected for chemical analysis. Natural variations in climate at a site requires an interpretation that distinguishes the effects of climate from the rates of acid generation. This distinction is important because precipitation determines the flushing rate and dilution of acid products but may not affect acid-generation rates. General parameters for evaluating water quality changes include pH, sulfate, acidity, and metals. To confirm the results of static tests the pH can be evaluated as follows:

- strongly acid generating if pH is less than 3.0,
- acid generating with possibly some neutralization if pH is between 3.0 and 5.0, and
- either not significantly acid generating or acid neutralization is overwhelming acid generation if pH is above 5.0.

Advantages:

Acid-generation and neutralization rates, under on-site climatic conditions, can be determined; control options such as adding limestone can be evaluated; the influence of bacteria can be monitored; the test has been used in Canada and appears reliable.

Disadvantages:

The test is relatively expensive and complex, results will vary as climatic conditions change, bacteria may not acclimatize to the sample, a test may need to run for a long time to meet program objectives, and interpreting the data is complex.

Generally accurate predictions of acid-generation potential can be obtained by the foregoing tests provided that assumptions upon which the tests are based hold. Ultimately however, the reliability of these tests, performed over a relatively short time in a laboratory, depends on the ability to correlate laboratory data with field behavior (Lawrence, 1990[2]).

CHAPTER III -- SUMMARY

Because of their simplistic assumptions, static tests should not be used alone to assess the acid-generation potential of mining waste. Static tests are more suited for a waste screening role, and their results should be confirmed by kinetic tests. Kinetic tests are more reliable than static tests in determining whether a mining waste will or will not generate acid; moreover, they can provide insight into both when a waste will begin to generate acid and the magnitude of the acid production. Consequently the most useful information concerning the potential threat mining waste poses to water quality will come from kinetic tests. Kinetic tests produce complex data that is difficult to interpret; therefore, the results of these tests should be evaluated by experienced professionals who understand the processes that these tests attempt to model. Our evaluation indicated that testing programs employing both static and kinetic tests are best suited for assessing the acid-generation potential of mining waste in California.

Because currently available tests provide generally reliable results and new tests and modifications to existing tests are being developed, there is no present need for the State Board to develop a new test for assessing the acid-generation potential of mining waste.

GLOSSARY

Acid generation. The phenomenon whereby acid is produced by the natural oxidation of sulfide minerals contained in rock which is exposed to air and moisture.

Acid-generation testing. Physical tests, carried out in either the laboratory or the field, that provide insight into the potential of a particular waste to generate acid.

Acid-generation control. Management techniques used to prevent or minimize acid generation. These techniques attempt to control the acid-generation processes or collect and treat the products of acid generation (leachate).

Acidic leachate. Low pH (pH less than 5) leachate formed by the drainage of liquids from waste or by the percolation of liquids through waste.

Alkaline. Relating to, or having the properties of a basic or alkali substance; *esp*: having a pH greater than 7.

Biologically controlled acid generation. The phenomenon whereby the rate of acid generated from sulfide minerals is controlled primarily by the bacterium *Thiobacillus ferrooxidans.*

Carbonate minerals. A mineral compound characterized by an anionic structure of CO_3^{-2}. Calcite, aragonite, and dolomite are examples of carbonate minerals.

Carbonate neutralization. The technique of neutralizing acidic leachate by the addition of carbonate minerals.

Crystallinity. The degree to which a rock or mineral is crystalline; i.e., having a regular, orderly, and repeated arrangement of atoms in a crystal.

Exothermic. Pertaining to a chemical reaction that occurs with the liberation of heat.

Iron disulfides. Minerals characterized by the chemical bonding of iron with sulfur. Pyrite, marcasite, and pyrrhotite are examples of iron disulfides.

Iron hydrolysis. Pertaining to a reaction where ionic iron reacts with water to form an iron hydroxide.

Iron hydroxides. A group of iron compounds, sparingly soluble when pH is above 4; these compounds are typically products of acid generation.

Kinetic tests. Laboratory or field tests which attempt to model the acid-generation process by controlled weathering.

Leachate. Liquid formed by the drainage of liquids from waste or by the percolation of liquids through waste.

Neutralization potential. The amount of acidity a waste can neutralize on the basis of naturally occurring minerals present in the waste.

Oxidation. The process of changing an element, ion, or compound from a lower to a higher positive valence, usually by removing one or more electrons.

pH: The notation used to express both acidity and alkalinity on a scale whose values run from 0 to 14 with 7 representing neutrality, numbers less than 7 increasing acidity, and numbers greater than 7 increasing alkalinity. The scale is based on the negative logarithm of the effective hydrogen-ion concentration.

Pyrite oxidation. The process whereby pyrite is oxidized by an oxidizing agent.

Silicate minerals. A mineral whose crystal structure contains SiO_4 tetrahedra.

Static tests. Laboratory tests that attempt to model the acid-generation process on the basis of the relative masses of acid-producing and acid-neutralizing minerals in a waste.

Sulfate. A compound characterized by the sulfate radical SO_4.

Sulfuric acid. A strong acid, H_2SO_4, which is a vigorous oxidizing and dehydrating agent.

Temporal variation. Pertains to the variation of a particular parameter (e.g., acid-generation rates or water quality) as a function of time.

Tonnes. A metric ton, a unit of measure which consists of one-thousand kilograms.

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